High speed plastic optical fiber data links using LEDs

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***Abstract*-Plastic optical fiber (POF) data links have been widely viewed as a cost- and energy- effective solutions for short-reach Gigabit data communications such as in-home and automotive networks. POF also has excellent compatibility with low-cost light-emitting-diodes (LEDs). In this paper, we demonstrate a 4 Gb/s single micro-LED (µLED) PAM-16 link and a record 4.7 Gb/s multiple µLEDs PAM-8 link by 1) use of avalanche photodiodes (APD) in combination with high order modulation formats; and 2) illumination of multiple µLEDs. Both digital implementation based on FPGA and analogue implementation are considered for real-time transmitters.**

I. INTRODUCTION

Plastic optical fiber (POF) data links are promising candidates for Gigabit short-reach optical data communications due to their low cost, ease of handling, and small bending radius. In addition, POF shows excellent compatibility with light-emitting-diodes (LEDs) due to its large core diameter that allows efficient coupling of light. Particularly, GaN-based micro-LED (µLED) arrays, consisting of individually-addressable pixels with diameters ≤100 µm, are of interest due to their high modulation bandwidth [1]. In addition, the high density of µLEDs allows several µLEDs to be coupled simultaneously into POF, allowing for analogue implementation of real-time pulse amplitude modulation (PAM) data, as will be reported in this paper.

The significant limitation of POF data links using µLEDs is the bandwidth of transceiver and fiber link. A straightforward approach to address this issue is to utilize advanced multi-level modulation formats with higher spectral efficiency relative to non-return to zero (NRZ) scheme. Recently, a number of advanced modulation formats have been proposed such as PAM [2-4], carrierless amplitude and phase (CAP) modulation [3,5] and optical orthogonal frequency division multiplexing (OFDM) [5,6]. In terms of transceiver complexity point of view, PAM has advantages compared to the other two schemes thus is considered in this work. Such modulation formats usually need higher signal to noise ratio (SNR) to achieve a required bit error rate (BER) due to use of multiple levels. This imposes stringent system optical link power budget by considering that the transmit power adheres to eye safety. Avalanche photodiode (APD) detectors have been proposed recently to address this issue [4] and it shows excellent power budget improvement compared to PIN detectors. Therefore, in this paper, we will show that APD enables PAM links with a large number of levels to achieve high bit rate. For a single µLED case, digital implementation of real time 4 Gb/s PAM-16 transmitter using field-programmable gate array (FPGA) is considered. For multiple µLEDs case, analogue implementation of real time 4.7 Gb/s PAM-8 transmitter is realized by using multiple pattern sources, which is the highest speed of such type of link to the best of our knowledge.

II. EXPERIMENT OF A SINGLE MICRO-LED SYSTEM

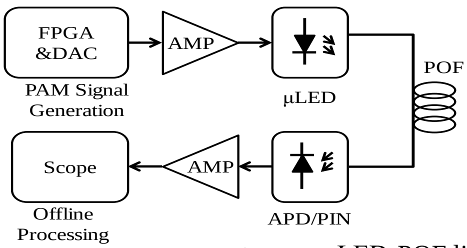

Figure 1. Experimental setup of a single µLED-POF link.

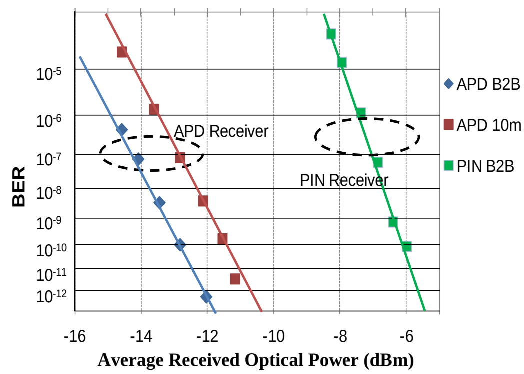

Figure 2. BER versus optical power measurements based on the system shown in Figure 1.

A. *Experimental Setup and System Parameters*

Figure 1 shows the experimental setup for the APD based single µLED-POF link. The real time PAM-16 signal is generated by an FPGA and a digital-to-analogue converter (DAC). The FPGA generates a 2^9-1 pseudorandom binary sequence (PRBS) that emulates the short run length codes used in data communications, and converts every 4 bits of the binary sequence into one corresponding PAM-16 symbol. The 16-bit DAC operates at 1 GSamples/s and produces an analogue PAM-16 signal with an aggregate data rate of 4 Gb/s. The PAM-16 signal is amplified to drive a 450 nm blue GaN µLED [1], which has a modulation bandwidth of about 150 MHz. The 1 mm-diameter POF is coupled with the µLED via a pair of lenses. The light output from the SI-POF is coupled into the 0.8 mm APD (First Sensor AD800-11) through a pair of aspheric lenses. The effective -3 dB bandwidth of the APD is about 650 MHz. The detected signal is then amplified by a low noise amplifier (LNA) and then captured by a digital communication analyzer for further offline processing based on feed-forward equalization (FFE) and decision feedback equalization (DFE). A similar link using a PIN detector (Femto HAS-X-S-1G4-SI) is considered for comparison.

B. Experimental Results

Figure 2 presents the BER performance of the optical back-to-back link and the 10 m POF link. For comparison, the BER curve obtained for the back-to-back link with the PIN receiver is also shown. Error-free (BER<10^{-12}) data transmission is achieved and sensitivities at BER=10^{-12} of -12 dBm and -10.8 dBm are obtained for the optical back-to-back and 10 m SI-POF links respectively. By using PIN, however, error-free transmission for back to back case requires -5.7 dBm optical power, indicating that the use of an APD brings about a 6.3 dB improvement in system power margin.

III. Experiment of Multiple micro-LED System

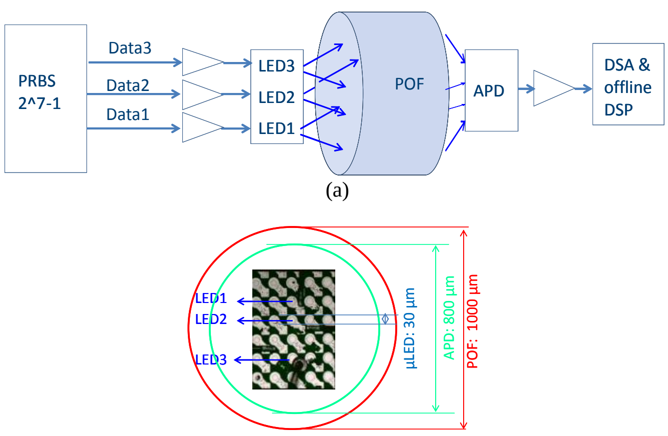

Figure 3. (a) Experimental setup of a multiple µLEDs-POF link, and (b) the microscope photo of the multiple µLEDs chip and size comparison of µLEDs, POF and APD.

A. Experimental Setup

Figure 3(a) depicts the experimental setup for the APD based multiple µLEDs-POF link. Three decorralated 2^7-1 PRBS sources from a pattern generator are amplified/attenuated so that their relative peak to peak amplitudes satisfy 4:2:1 ratio. The three signals together with properly configured bias currents drive three µLEDs as marked in Fig. 3(b) simultaneously. The three µLEDs of an µLED array have similar size (40nm diameter) and bandwidth (~150 MHz) and geographically spaced (center-to-ceneter) with 100 µm and 200µm distances as shown in Fig. 3(b). Eight distinguishable optical intensity levels with even space are observed, i.e., optical PAM-8, when the RF signal symbol rate is close to the bandwidth of µLEDs. However, here we set the pattern source symbol rate at 1.5625 GBaud. Therefore the optical PAM-8 signal has a bit rate of about 4.7 Gb/s. As shown in Fig. 3(b), the µLEDs have much smaller size compared to the 1 mm POF core; this can achieve efficient light coupling from multiple µLEDs to the POF by using the experiment optical setup of the single µLED-POF link. The receiver setup is identical to that shown in Fig. 1.

B. Experimental Results

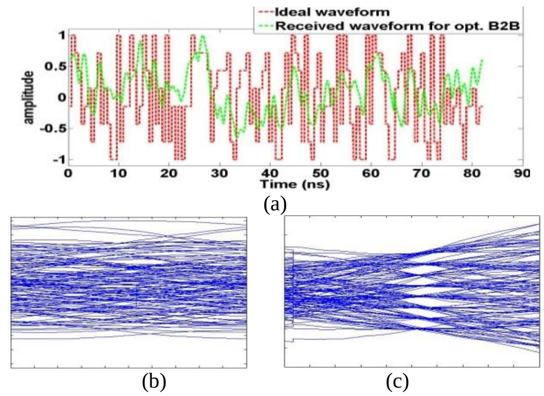

Figure 4. (a) captured waveform, and the eye diagram of captured waveform (b) before equalization and (c) after equalization.

Figure 4 presents the captured waveform and eye diagrams for a 1 m POF link. As shown in Fig. 4(a), the captured 4.7 Gb/s PAM-8 waveform shows strong distortion due to narrow transceiver bandwidth compared with an ideal waveform that is a sum of the three RF signals in transmitter. Thus the eye diagram is completely closed as indicated in Fig. 4(b). By implementing FFE and DFE, the eye diagram can be recovered properly. More results will be presented in conference.

IV. Conclusions

We have experimentally demonstrated high speed POF data links using µLEDs and APD. Two transmitters have been realized including a FPGA-based real time 4 Gb/s single µLED PAM-16 transmitter and a record analogue 4.7 Gb/s multiple µLEDs PAM-8 transmitter.

Acknowledgment

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